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(54) CLUTCH FILL VOLUME LEARNING STRATEGY FOR TRANSMISSION CONTROL

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(51) Int. Cl.
G06F 17/00 (2006.01)

(52) U.S. Cl. 701/51; 477/70; 701/59

(58) Field of Classification Search .... None
See application file for complete search history.

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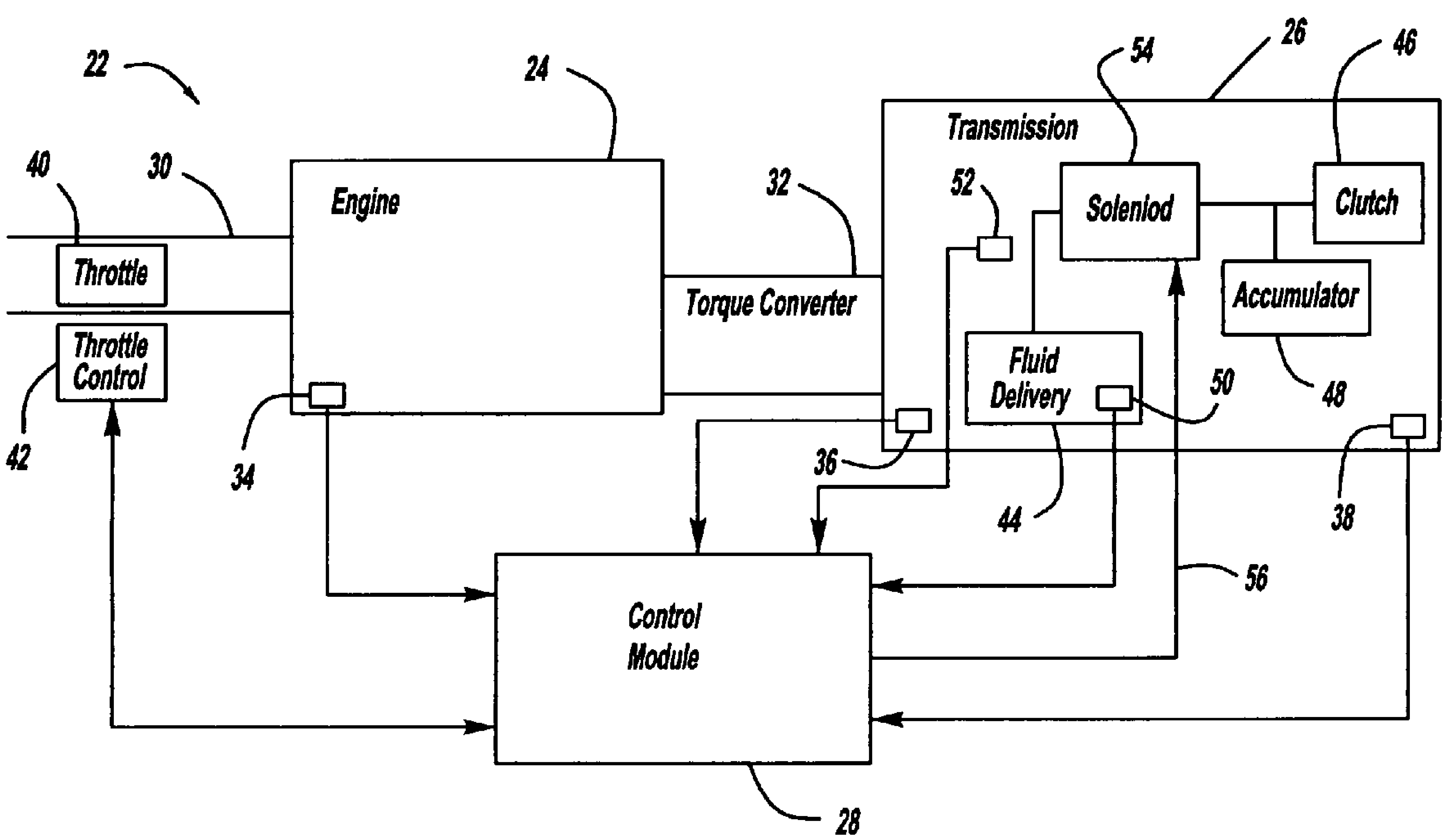
(57) ABSTRACT

A transmission control system for a transmission including a first gear engagement element that receives a fluid and engages a first gear. The system includes an electromagnetic actuator that receives a control signal and that selectively interrupts flow of the fluid to the first gear engagement element based on a value of the control signal. The system also includes a control module that generates the control signal and that adjusts the value of the control signal so that the first gear engagement element produces a first torque sufficient to hold the first gear. The control module detects a target volume of the fluid when the first gear engagement element produces the first torque. Also, the control module extrapolates a current fill volume (i.e., the volume at which the first gear engagement element begins to produce torque during a shift) of the first gear engagement element from the target volume.

20 Claims, 8 Drawing Sheets



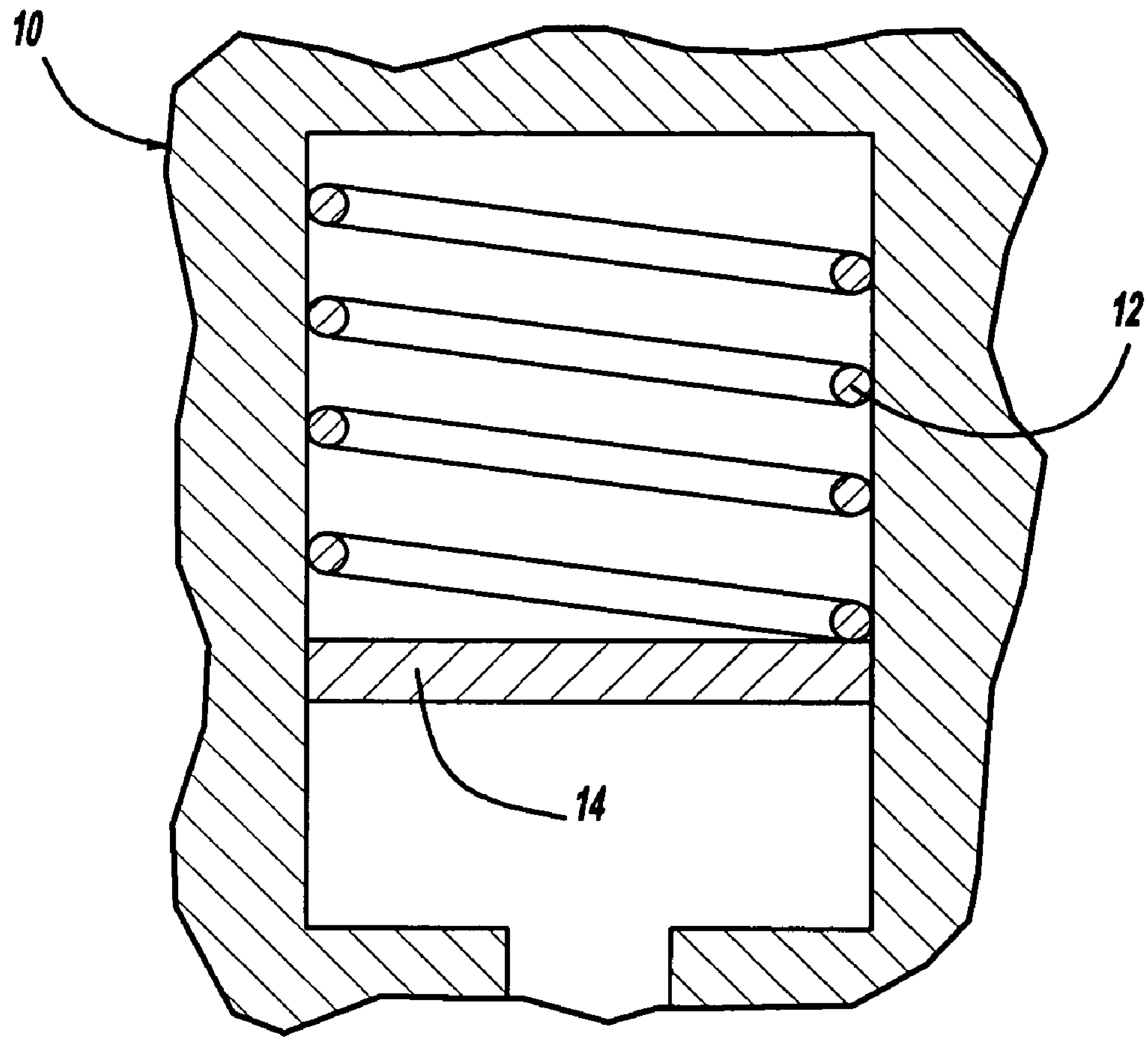


FIG - 1
Prior Art

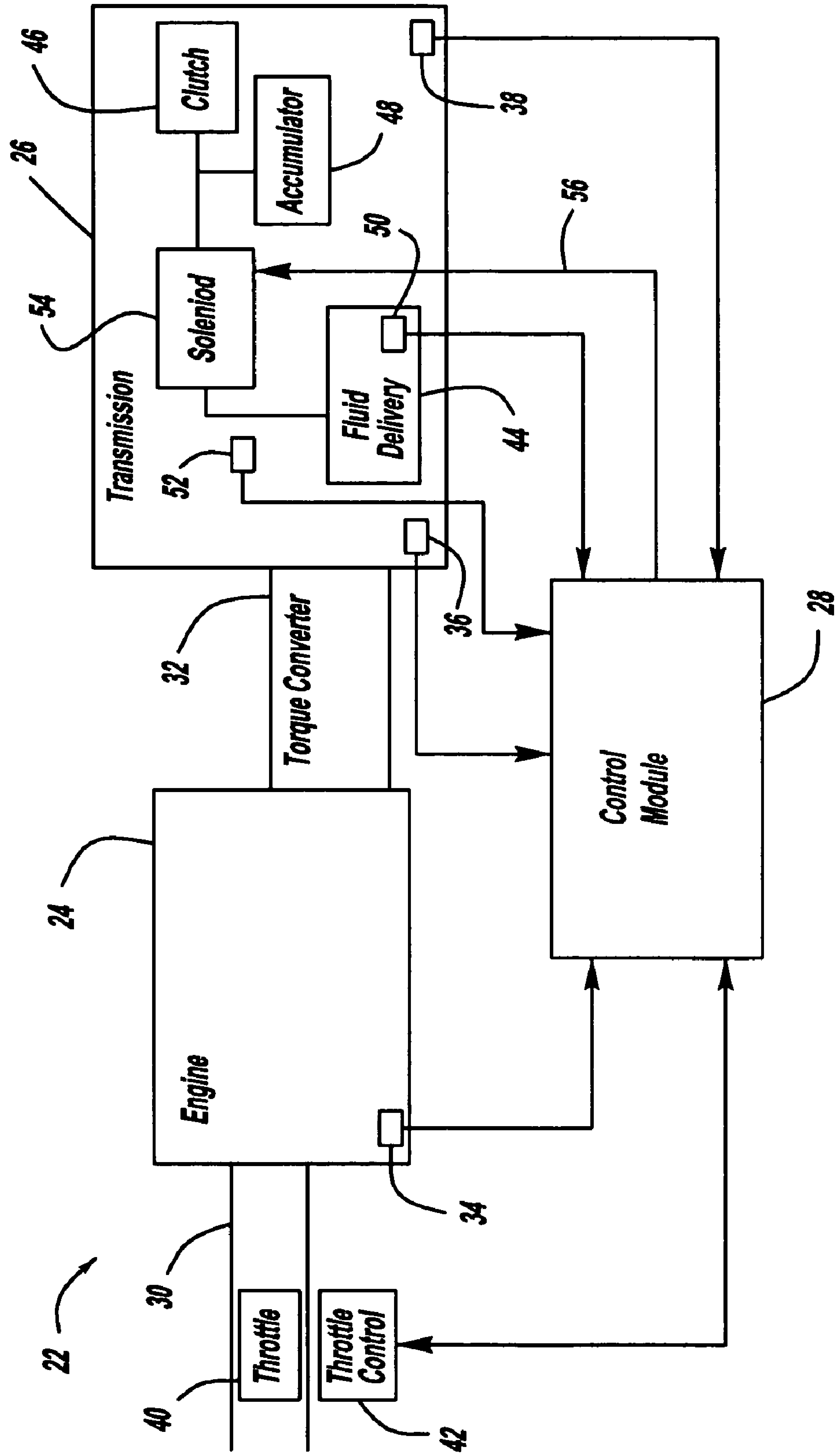

Transmission
Clutch
Accumulator
Soleniod
Fluid Delivery
Torque Converter
Engine
Control Module
Throttle
Throttle Control
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
54
56

FIG - 2

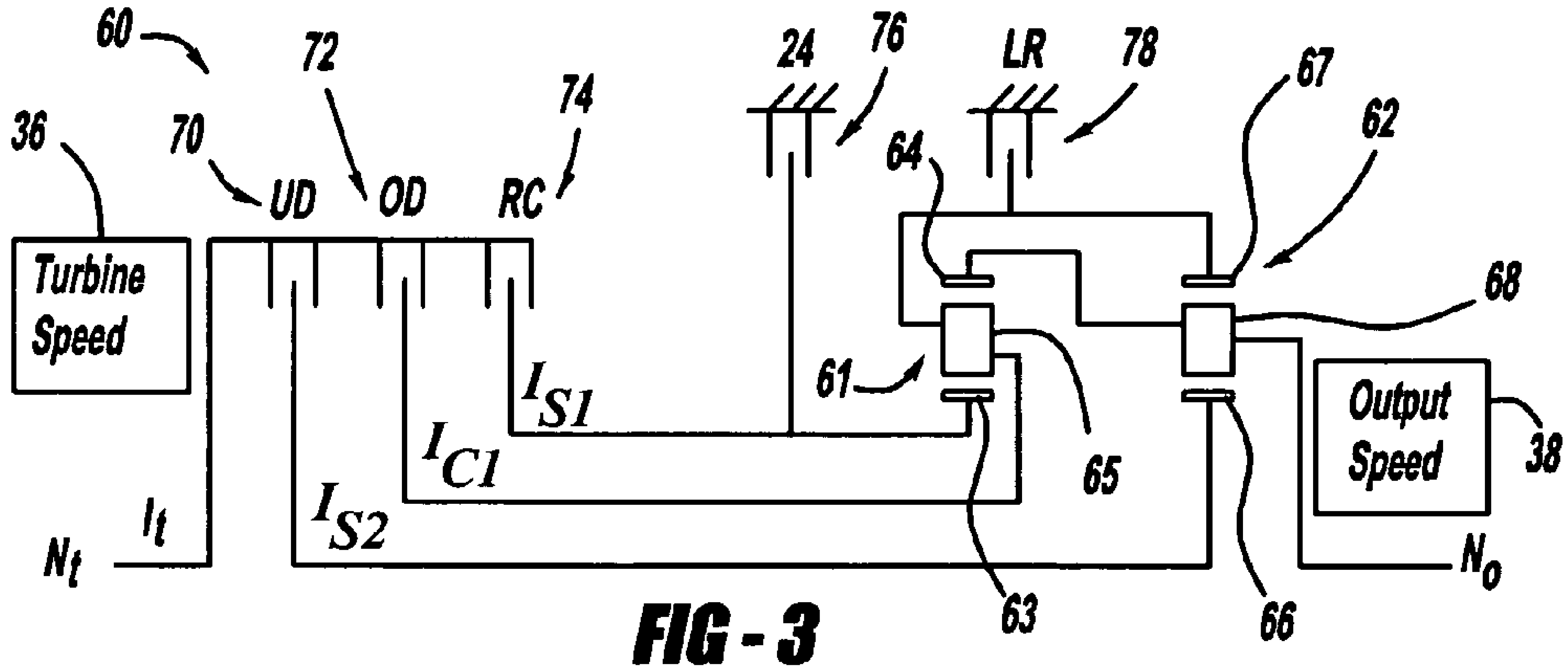

60
72
74
24
76
LR
78
67
62
36
70
UD
OD
RC
64
Turbine Speed
68
61
65
Output Speed
38
I_{S1}
I_{C1}
I_{S2}
N_t
I_t
63
66
N_o

FIG - 3

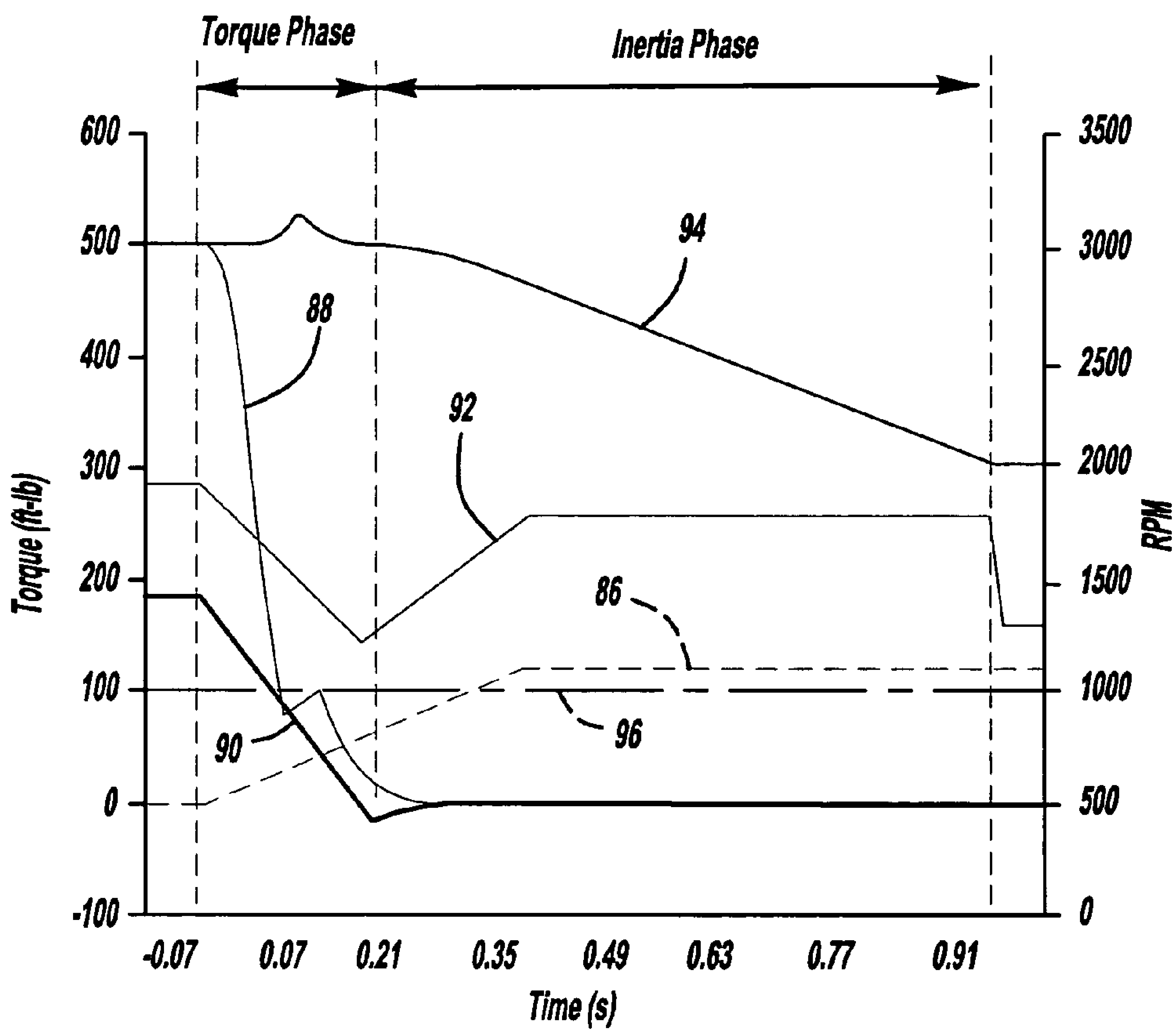
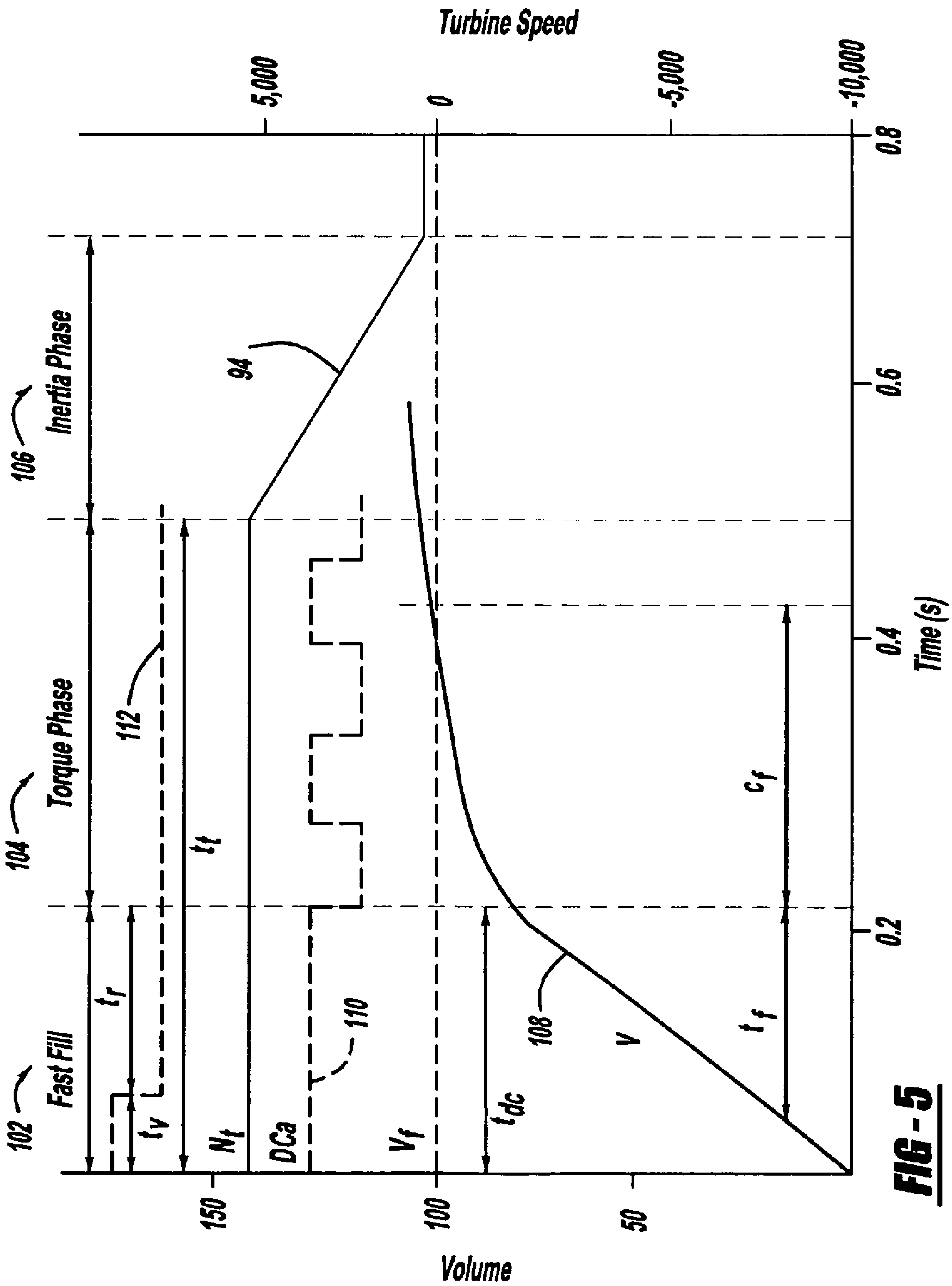
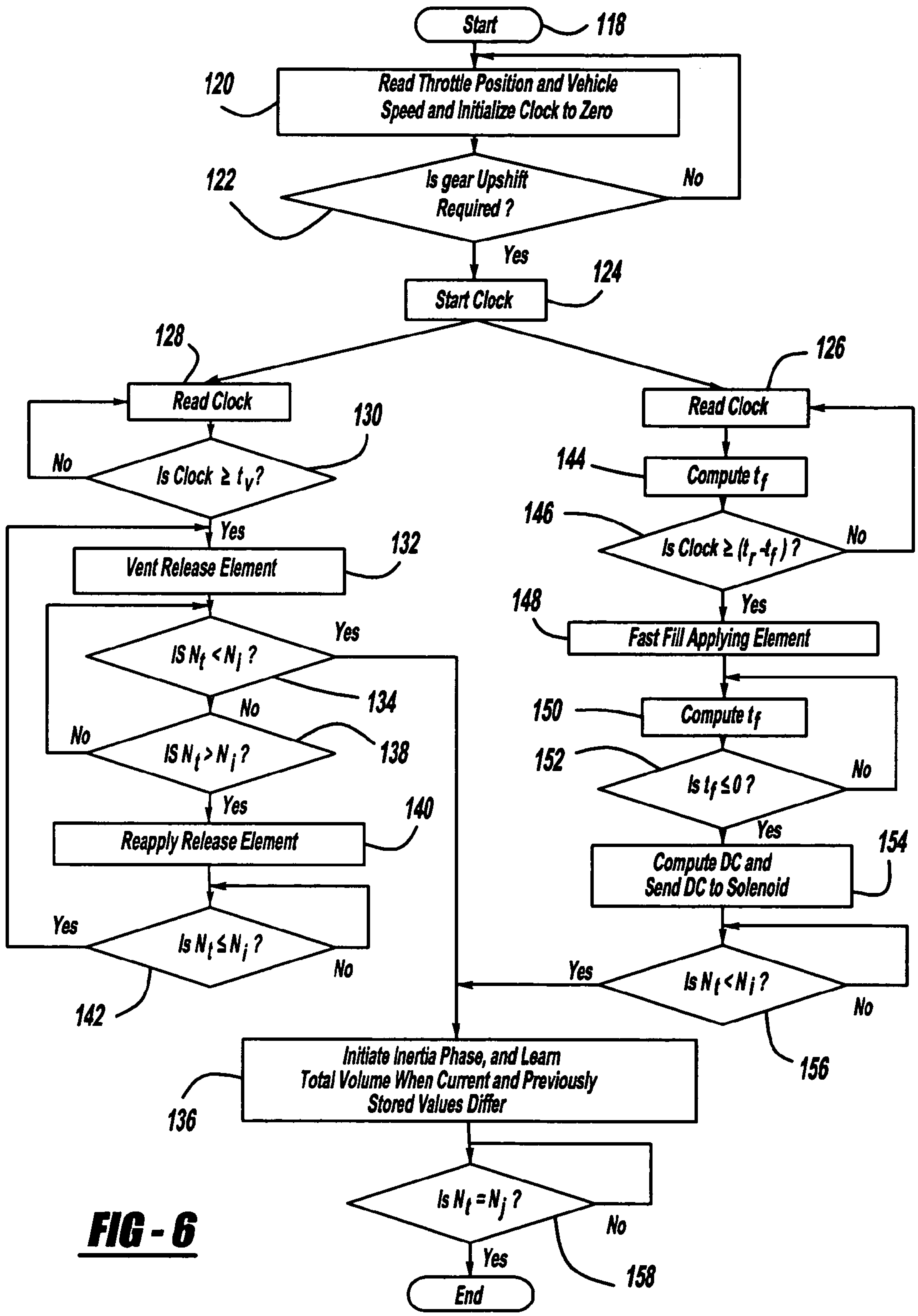

Torque Phase
Inertia Phase
600
500
400
300
200
100
0
-100
Torque (ft-lb)
3500
3000
2500
2000
1500
1000
500
0
RPM
94
88
92
86
96
90
-0.07
0.07
0.21
0.35
0.49
0.63
0.77
0.91
Time (s)

FIG - 4



Turbine Speed
5,000
0
-5,000
-10,000
Inertia Phase
Torque Phase
Fast Fill
102
104
106
94
112
110
108
t_r
t_v
t_t
N_t
DCa
V_f
t_{dc}
V
t_f
c_f
150
100
50
Volume
0.2
0.4
0.6
0.8
Time (s)

FIG - 5



Start
118
120
Read Throttle Position and Vehicle Speed and Initialize Clock to Zero
122
Is gear Upshift Required ?
No
Yes
Start Clock
124
128
Read Clock
130
No
Is Clock ≥ t_V?
Yes
132
Vent Release Element
Yes
IS N_t < N_i ?
134
No
No
IS N_t > N_i ?
138
Yes
140
Reapply Release Element
Yes
Is N_t ≤ N_i ?
No
142
126
Read Clock
144
Compute t_f
146
Is Clock ≥ (t_r - t_f) ?
No
Yes
148
Fast Fill Applying Element
150
Compute t_f
152
Is t_f ≤ 0 ?
No
Yes
154
Compute DC and Send DC to Solenoid
Yes
Is N_t < N_i ?
No
156
Initiate Inertia Phase, and Learn Total Volume When Current and Previously Stored Values Differ
136
Is N_t = N_j ?
No
Yes
158
End

FIG - 6

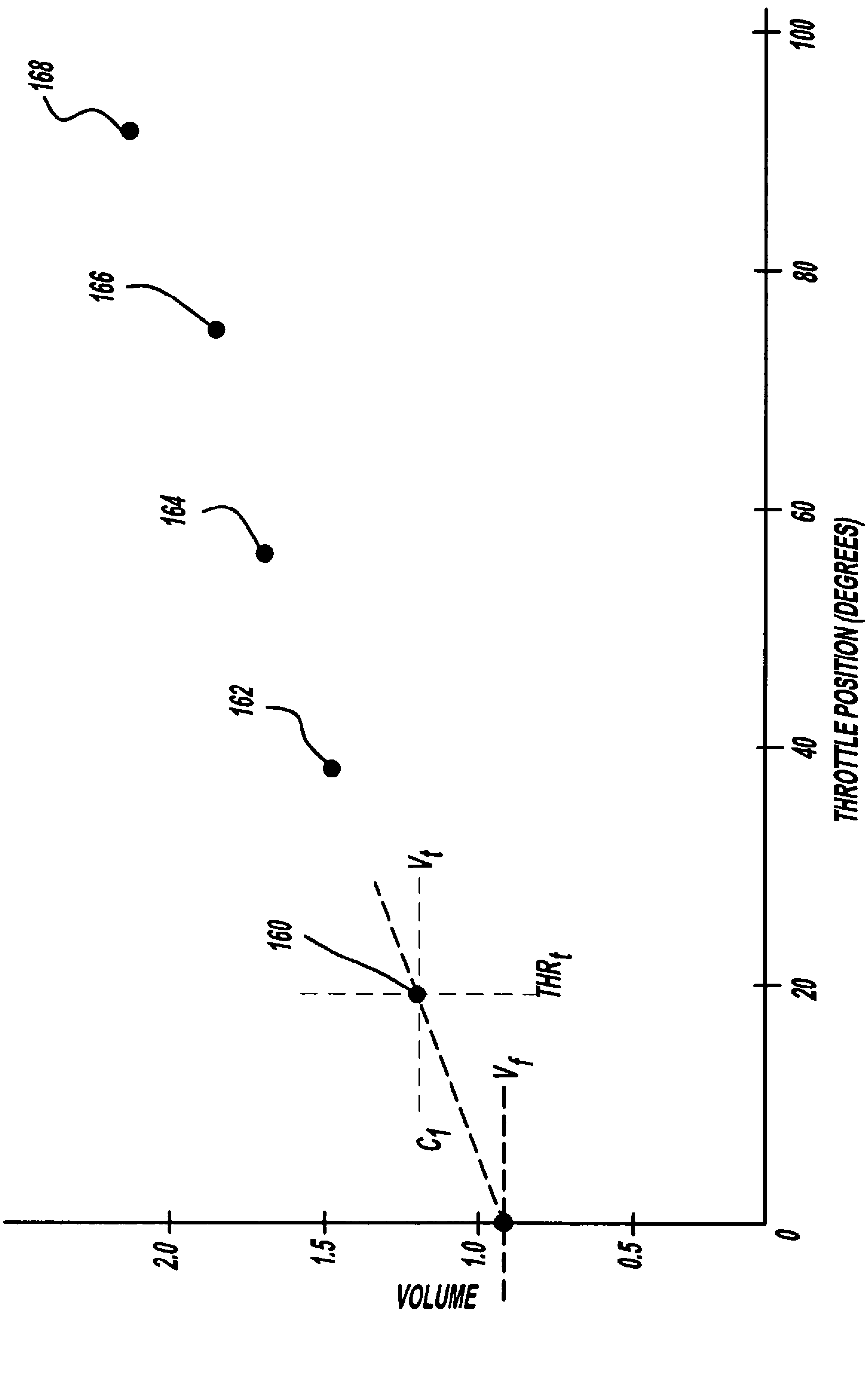

VOLUME
2.0
1.5
1.0
0.5
0
20
40
60
80
100
THROTTLE POSITION (DEGREES)
160
162
164
166
168
V_t
V_f
C_1
THR_t

FIG - 7

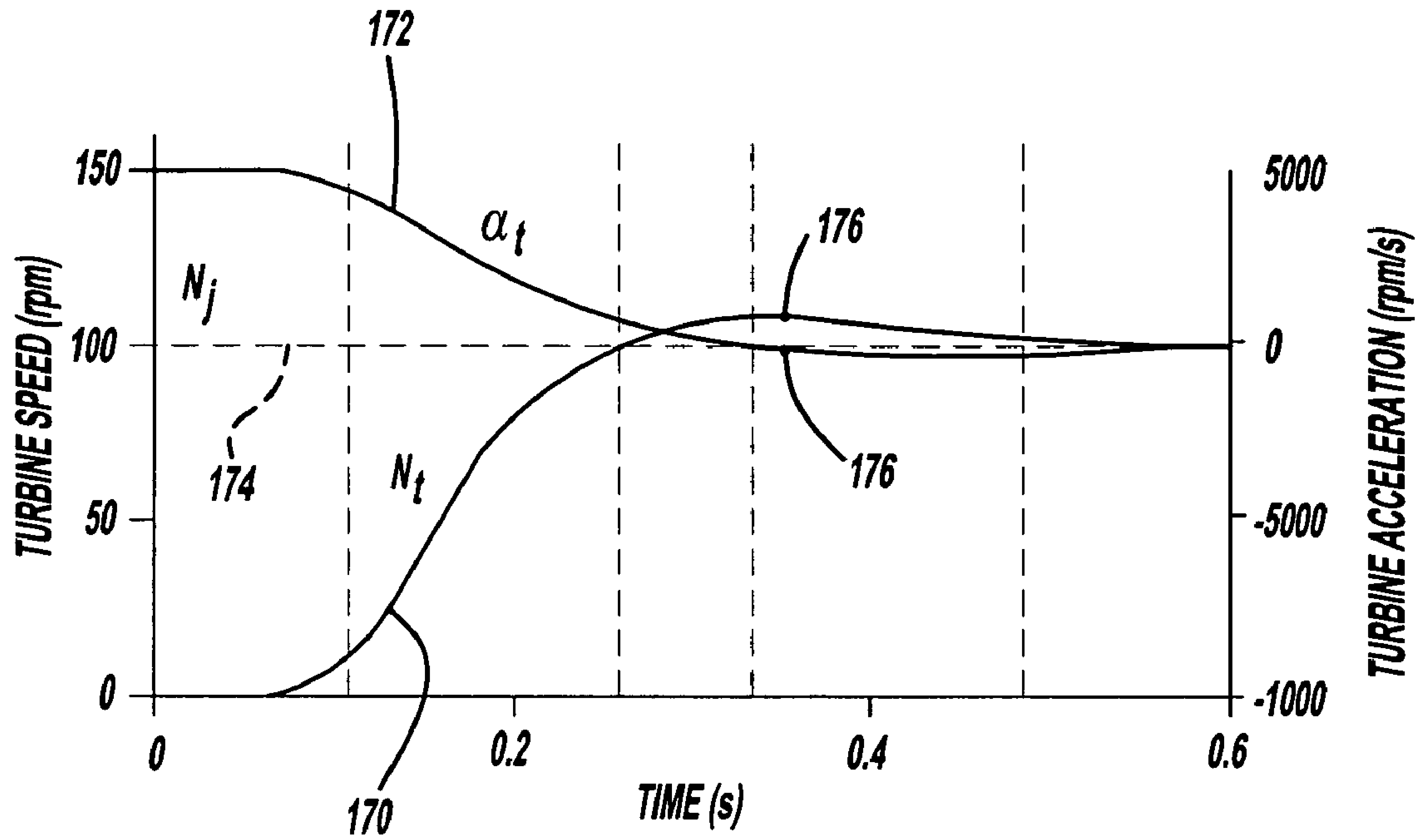

172
150
100
50
0
TURBINE SPEED (rpm)
N_j
174
α_t
N_t
176
176
170
5000
0
-5000
-1000
TURBINE ACCELERATION (rpm/s)
0
0.2
0.4
0.6
TIME (s)

FIG - 8

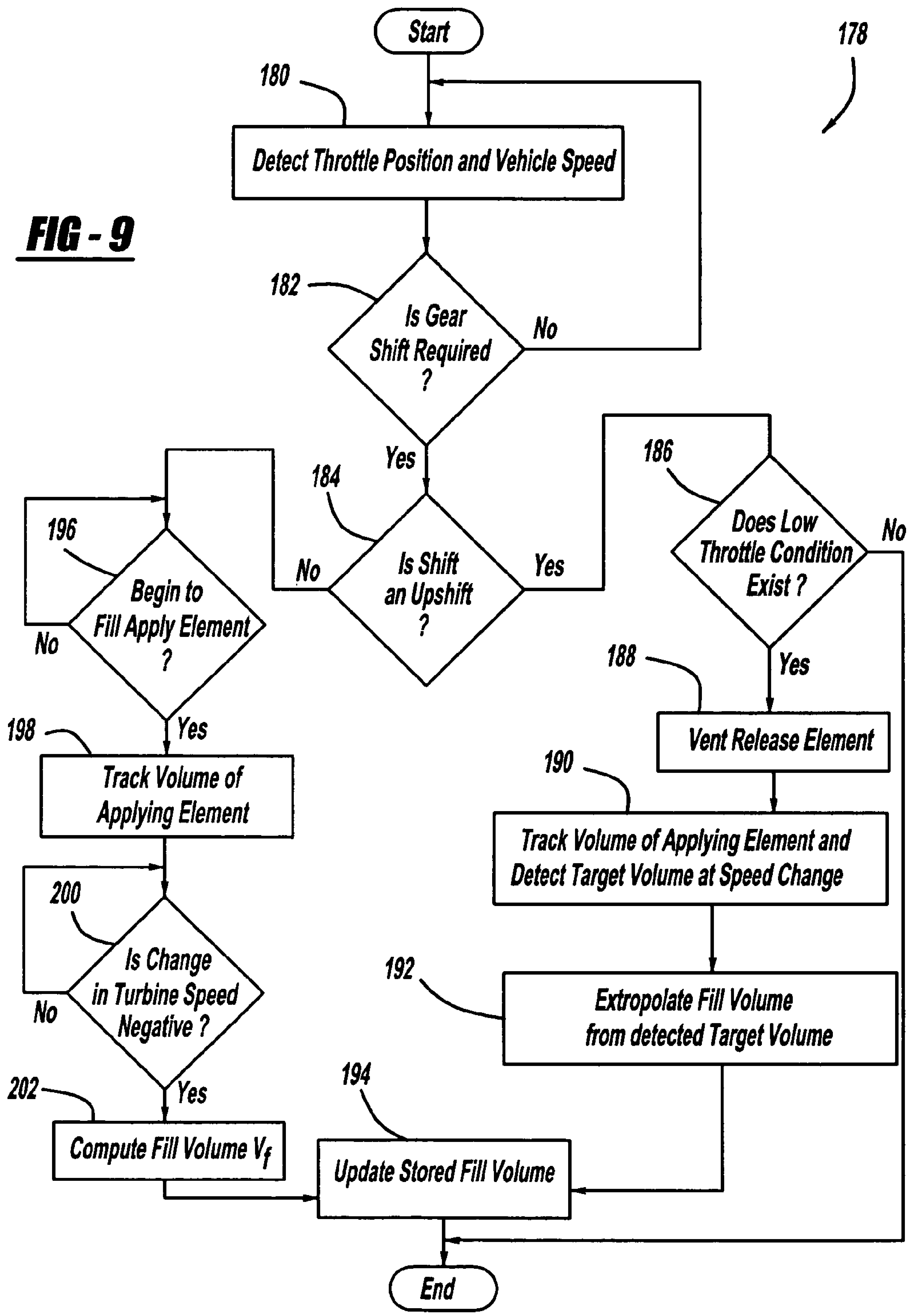

Start
178
180
Detect Throttle Position and Vehicle Speed
182
Is Gear Shift Required ?
No
Yes
184
Is Shift an Upshift ?
No
Yes
186
Does Low Throttle Condition Exist ?
No
Yes
188
Vent Release Element
190
Track Volume of Applying Element and Detect Target Volume at Speed Change
192
Extropolate Fill Volume from detected Target Volume
196
Begin to Fill Apply Element ?
No
Yes
198
Track Volume of Applying Element
200
Is Change in Turbine Speed Negative ?
No
Yes
202
Compute Fill Volume V_f
194
Update Stored Fill Volume
End

FIG - 9

CLUTCH FILL VOLUME LEARNING STRATEGY FOR TRANSMISSION CONTROL

FIELD

The present invention relates to transmission control systems, and more particularly to a clutch fill volume learning strategy for transmission control systems.

BACKGROUND

Due to relatively high instances of system inertia and delay in automotive transmissions, exclusively using feedback control of various components in automotive transmissions may not be sufficient for certain transient schemes. In such transient cases, feedforward control may be used to anticipate system changes. For example, mixed feedforward and feedback control can be used for a smooth upshift in an automatic transmission without causing significant "feel" issues for the driver, thereby improving overall shift quality.

An upshift operation in an automatic transmission typically involves a first clutch (or releasing element) that disengages from a first gear while a second clutch (or applying element) engages a second gear. A third clutch remains engaged during the upshift operation. Therefore, at least two clutches are typically engaged during each gear level of an automatic transmission. For example, an upshift in a 4-speed automatic transmission may be a 1-2 shift, a 2-3 shift, and/or a 3-4 shift.

Referring now to FIG. **1**, clutches in automatic transmissions are typically actuated by pressure from fluid such as oil. Oil fills the clutch cavity including a piston and displaces the piston to engage the clutch. Automatic transmission systems also typically include accumulators **10** for each clutch. As oil fills the cavity including the clutch it also fills the accumulator **10**. The accumulator **10** includes a spring **12** that is compressed when a piston **14** in the accumulator **10** is displaced by pressure from the oil. The oil begins to displace the piston **14** after all of the empty space in the accumulator **10** is filled with oil and the pressure of the oil increases. Therefore, accumulators **10** reduce the sensitivity of torque variations during the torque phase of an upshift.

A solenoid controls the flow rate of oil to the accumulator **10** and the associated clutch. The duty cycle of a control signal applied to the solenoid determines the fraction of time during which the solenoid valve is open or closed. Thus, the solenoid controls the flow rate and ultimately the pressure of the oil. Also, the accumulator **10** makes the pressure response slower and more difficult to predict. The calculated volume of oil present in the accumulator **10** at a given time is an indicator of the capacity of the clutch at that time. Therefore, the calculated volume can be used for control purposes.

However, the calculated volume may vary throughout the life of the transmission due to wear of the clutch and/or other factors. Transmission control systems have been developed that adjust the duty cycle of the solenoid over the operating life of the transmission to thereby account for changes in the system and to maintain smooth shifting. For instance, applicant's patent application, entitled "TARGET VOLUME BASED TORQUE PHASE CONTROL DURING UPSHIFT", Ser. No. 11/222,066, filed Sep. 8, 2005, discloses such a system. Applicant's patent, entitled "MODEL BASED KICKDOWN SHIFT METHOD FOR CLUTCH TO CLUTCH SHIFT TRANSMISSIONS WITH ACCUMULATORS", U.S. Pat. No. 6,978,201, which issued Dec. 20, 2005, also discloses such a system.

The fill volume (i.e., the volume of oil at which an applying element begins to produce torque during a shift) of each clutch is used by the control logic of these systems to effectuate gear shifts. However, the fill volumes can vary over the lifetime of the vehicle due to wear and/or other factors. As a result, gear shifting may be detrimentally affected due to inaccurate fill volume values stored in memory in the system. Accordingly, there remains a need for a means of accurately measuring updating stored values of the fill volume of a transmission.

SUMMARY

A first object of the present invention provides a transmission control system for a transmission including a first gear engagement element that receives a fluid and engages a first gear in response to pressure from the fluid. The system includes an electromagnetic actuator that receives a control signal and that selectively interrupts flow of the fluid to the first gear engagement element based on a value of the control signal. The system also includes a control module that generates the control signal and that adjusts the value of the control signal so that the first gear engagement element produces a first torque sufficient to hold the first gear. The control module detects a target volume of the fluid when the first gear engagement element produces the first torque. Also, the control module extrapolates a current fill volume (i.e., the volume at which the first gear engagement element begins to produce torque during a shift) of the first gear engagement element from the target volume.

In another aspect, the present invention provides a transmission control system for a transmission including first and second gear engagement elements that receive fluid and engage first and second gears, respectively, in response to pressure from the fluid. The transmission control system includes an electromagnetic actuator that receives a control signal and that selectively interrupts flow of the fluid to the first gear engagement element based on a value of the control signal. The system also includes a control module that generates the control signal and that adjusts the value of the control signal so that the first gear engagement element produces a first torque sufficient to hold the first gear during an upshift. The control module detects a target volume of the fluid when the first gear engagement element produces the first torque. Also, the control module extrapolates a current fill volume of the first gear engagement element from the target volume. In addition, the control module detects a current fill volume of the second gear engagement element by detecting a current volume of the fluid received by the second gear engagement element when the second gear engagement element begins to produce torque during a downshift. The control module only extrapolates the current fill volume of the first gear engagement when either the position of the throttle blade is less than a predetermined value or the transmission input torque is less than a predetermined value.

In still another aspect, the present invention provides a method for operating a transmission control system for a transmission including a first gear engagement element that receives fluid and engages a first gear in response to pressure from the fluid. The method includes the step of selectively interrupting flow of the fluid to the first gear engagement element based on a value of a control signal. The method also includes the step of adjusting the value of the control signal so that the first gear engagement element produces a first torque sufficient to hold the first gear. The method further includes the step of detecting a target volume of the fluid when the first gear engagement element produces the first torque. In addition, the method includes the step of extrapolating a current fill volume of the first gear engagement element from the target volume.

Further areas of applicability of the present disclosure will become apparent from the detailed description provided hereinafter. It should be understood that the detailed description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure will become more fully understood from the detailed description and the accompanying drawings, wherein:

FIG. **1** illustrates an exemplary accumulator for an automatic transmission according to the prior art;

FIG. **2** is a functional block diagram of an automatic transmission control system for a vehicle including a control module that communicates with vehicle sensors according to an exemplary embodiment of the present invention;

FIG. **3** illustrates an automatic transmission system including clutches that are engaged and disengaged during gear shifts according to an exemplary embodiment of the present invention;

FIG. **4** is a graph illustrating turbine speed and torques exhibited at a plurality of components in an automatic transmission as a function of time and during an upshift operation according to an exemplary embodiment of the present invention;

FIG. **5** is a graph illustrating accumulator volume and a duty cycle of a solenoid as a function of time during an upshift operation according to an exemplary embodiment of the present invention;

FIG. **6** is a flowchart illustrating steps performed by the control module of FIG. **2** to execute an upshift operation and utilize target volume torque phase control according to an exemplary embodiment of the present invention;

FIG. **7** is a graph illustrating the relationship between throttle position and volume in a clutch hydraulic system according to an exemplary embodiment of the present invention;

FIG. **8** is a graph illustrating a downshift of a transmission according to an exemplary embodiment of the present invention; and

FIG. **9** is a flowchart illustrating a method of fill volume learning for a transmission control system according to an exemplary embodiment of the present invention.

DETAILED DESCRIPTION

The following description is merely exemplary in nature and is in no way intended to limit the scope of the disclosure, its application, or uses.

Upshift operations are commonly divided into a torque phase and an inertia phase. During the torque phase of an upshift, a change in turbine speed typically does not occur. The torque of the releasing element decreases to zero from an initial capacity, and the torque of an applying element picks up the entire load. Since the applying element provides less leverage, the output torque decreases when the applying element picks up the entire load. A mismatch in capacity between the releasing and applying elements can result in unstable operation. For example, if the releasing element disengages too soon, turbine speed flare and bump-along may occur. When bump-along occurs an applying clutch that applies too slowly may disengage and attempt to reengage until turbine speed flare is suppressed, which can cause vehicle shudder. When turbine speed flare occurs, a power flow disruption exists between the input and output of the transmission, the engine speed quickly rises, and output torque drops.

Additionally, if the applying element applies too soon, three clutches may be engaged at the same time, acting as a brake. Therefore, the torque phase is a critical part of the upshift, and precision control of automatic transmission components is essential for desirable shift quality. For example, transmission control systems determine when to shift and control the timing of applying and releasing clutches in order to ensure smooth shift transitions.

Target volume torque phase control according to the present invention is proposed to accurately control the duty cycles of solenoids so that the transition from torque phase to inertia phase is smooth, bump free, and completed within a predetermined time period. The present invention uses a model-based approach to identify speed and torque dynamics for each transmission element during transmission shift operations. Target volumes of accumulators required for an associated clutch to produce torque necessary to hold gear are computed and updated as necessary.

Since the dynamics of the transmission change with different speed and acceleration, the target volumes are stored and updated with respect to a current position of the throttle blade when the inertia phase begins. The control module computes continuously variable duty cycles for the solenoids that are utilized during the torque phase based on the stored target volumes so that upshift operations remain stable as conditions of the transmission change over time.

Referring now to FIG. **2**, an automatic transmission control system **22** includes an engine **24**, an automatic transmission **26**, and a control module **28**. The engine **24** receives air through an inlet **30**, and the air mixes with fuel in cylinders of the engine **24**. The air/fuel mixture is ignited in the cylinders to generate rotational power on an engine shaft. The engine **24** drives the transmission **26** through a torque converter **32**, and the transmission **26** drives a vehicle through a gear ratio. The control module **28** communicates with various sensors and controls gear shifting in the transmission **26**. For example, an engine speed sensor **34** in the engine **24** generates an engine speed signal and transmits the engine speed signal to the control module **28**. A turbine speed sensor **36** in the transmission **26** generates a turbine speed signal and transmits the turbine speed signal to the control module **28**.

An output speed sensor **38** in the transmission **26** generates an output speed signal and transmits the output speed signal to the control module **28**. A throttle blade **40** in the inlet controls a flow rate of air to the engine **24**. A position of the throttle blade **40** typically relates to a desired speed and/or acceleration of the vehicle by the driver. The control module **28** communicates with a throttle control module **42** in order to detect and/or adjust a position of the throttle blade **40**. For example, the throttle control module **42** may include a throttle position sensor and/or an electronic throttle controller.

A fluid delivery system **44** in the transmission **26** delivers oil to a clutch **46** and an accumulator **48** during shift maneuvers. For example, the fluid delivery system **44** may include a sump with oil, a pump, and/or other hydraulic system components. A fluid temperature sensor **50** in the fluid delivery system **44** generates a fluid temperature signal and transmits the fluid temperature signal to the control module **28**. A line pressure sensor **52** in the transmission **26** generates a line pressure signal and transmits the line pressure signal to the control module **28**. An electromagnetic actuator, such as a solenoid **54**, is located between the fluid delivery system **44** and the clutch **46** and accumulator **48**.

The solenoid **54** selectively interrupts the flow of oil to the clutch **46** and accumulator **48** in response to the duty cycle of an applied control signal **56**. Therefore, the solenoid **54** controls the flow rate and pressure of the oil delivered to the clutch **46** and accumulator **48**. The control module **28** generates the control signal **56** and transmits the control signal **56** to the solenoid **54**. While a single clutch **46** is illustrated in FIG. **2**, those skilled in the art can appreciate that the transmission **26** includes multiple clutches **46** that are selectively engaged and disengaged in order to shift between gears.

As the accumulator **48** fills with oil, the volume of the accumulator **48** varies, which changes the clutch pressure based on the accumulator spring rate. The control module **28** determines the torque required by the transmission element clutches **46** to keep the transmission **26** in gear. In an exemplary embodiment, the control module **28** determines the required torque based on engine speed, accumulator volume, input torque from the turbine, inertia of the engaged elements **46** in the transmission **26**, and output acceleration of the transmission **26**. The control module **28** also computes a continuously variable duty cycle of the control signal **56** for the solenoid **54**. In an exemplary embodiment, the control module **28** computes the duty cycle based on the relationship between the torque and pressure of the individual element clutches **46** as well as the relationship between accumulator pressure and accumulator volume change.

Referring now to FIG. **3**, upshift operations are controlled based on target volume control and continuously variable solenoid duty cycles. An exemplary automatic transmission **60** includes planetary elements **61** and **62** and element clutches **70**, **72**, **74**, **76**, and **78**. Planetary element **61** includes sun gear **63**, ring gear **64**, and carrier **65**, and planetary element **62** includes sun gear **66**, ring gear **67**, and carrier **68**. One or more of the clutches **70**, **72**, **74**, **76**, and/or **78** interact with one or more of the planetary elements **61** and/or **62** in order to select a gear ratio of the transmission **60**. For example, when clutch **70** is in contact with sun gear **66** and clutch **78** is in contact with carrier **65** and ring gear **67**, 1^{st} gear is selected. However, in order to select 2^{nd} gear, clutch **70** must be in contact with sun gear **66** and clutch **76** must be in contact with sun gear **63**. Therefore, in order for the transmission **60** to upshift from 1^{st} gear to 2^{nd} gear, clutch **78** must release carrier **65** and ring gear **67** and clutch **76** must be applied to sun gear **63**.

In any particular upshift, the element clutches **70**, **76**, and **78** that are releasing are referred to as releasing element clutches, and element clutches **72** and **76** that are applied during an upshift are referred to as applying element clutches. Hereinafter, all references to the releasing element refer to clutch **78** and all references to the applying element refer to clutch **76** with respect to a 1-2 upshift. Although the following strategy and associated equations refer to a 1-2 upshift, it should be understood that analogous calculations can be applied to other upshifts such as 2-3 and/or 3-4 upshifts.

Referring now to FIG. **4**, the torque phase begins when the torque (identified by **86**) of the applying element **76** begins to increase. At the beginning of an upshift, the applying element **76** begins to fill with oil, which increases the torque **86** of the applying element **76**. The releasing element **78** is vented, which makes the capacity of the releasing element **78** (identified by **88**) quickly fall. As the torque of the applying element **76** increases, the torque of the releasing element **78** (identified by **90**) begins to decrease from a value necessary to hold the transmission **60** in 1^{st} gear.

Ideally, both the capacity **88** and torque **90** of the releasing element **78** decrease to zero by the end of the torque phase. However, as shown in FIG. **4**, the capacity **88** of the releasing element **78** may decrease below the torque **90** of the releasing element **78**. In this case bump-along occurs, which causes the turbine speed **94** to increase and the releasing element **78** is temporarily reapplied until the turbine speed **94** returns to an initial gear value. The output torque of the transmission **60** (identified by **92**) also drops due to less leverage of the 2^{nd} gear ratio during the torque phase until the turbine speed **94** starts to drop as the applying element **76** begins to pick up all of the load.

When the torque **86** of the applying element **76** increases beyond a certain value, the applying element **76** begins to take on the load of the transmission **60**. Ideally, this is timed so that the upshift is not detected by the driver by way of uncomfortable delays or jerks. When the applying element **76** takes on the transmission load, the speed of the turbine (identified by **94**) drops and the output torque **92** of the transmission **60** increases because of the inertia force from all of the moving elements from the 1^{st} gear ratio to the 2^{nd} gear ratio. This marks the end of the torque phase and the beginning of the inertia phase. The output torque **92** increases until the torque **86** of the applying element **76** is sufficient to maintain a constant predefined turbine acceleration **94**. Eventually, the turbine speed **94** reaches the 2^{nd} gear ratio, which marks the end of the inertia phase as well as the entire shift event. The input torque of the transmission **60** (identified by **96**) remains constant during the upshift in the system illustrated in FIG. **4**. However, the input torque **96** may fluctuate during upshifts in other systems.

Based on the dynamic model discussed above and the speed relation between gears, the required torque of an applying element **76** during the torque phase of an upshift is computed. For example, the required torque T_{24} for applying element **76** during a 1-2 upshift is $T_{24}=C_1T_t-C_2T_{LR}-[C_3(I_T+I_{S2})+C_4I_{s1}]\alpha_o$. In the formula T_t is the output torque of the turbine, T_{LR} is the torque of releasing element **78** while holding the transmission **60** in 1^{st} gear, α_o is the output shaft acceleration, and C_1-C_4 are constants.

However, torque is not the actual control actuator in the transmission control system **22** of the present invention. The duty cycle of the solenoid **54** is the control force that changes the torque of a clutch **76**. Therefore, the relationship between the flow rate produced by the duty cycle of the solenoid **54** and the torque of the applying element **76** is examined.

First, there is a relationship between accumulator volume V_a and applying element pressure. The calculated applying element pressure is

$$P_{24a} = K_a\frac{V_a - V_{amin}}{A_a^2} + P_{MIN},$$

where K_a is the accumulator spring coefficient, V_{amin} is the minimum accumulator volume, A_a is the accumulator piston area, and P_{MIN} is the pre-loaded accumulator pressure.

Based on the applying element pressure, the required torque T_{24} for the applying element **76** is computed. The applying element torque is $T_{24}=P_{24}A_p\mu_fR_{eff}n_{4c}$, where A_p is the friction material area, μ_f is the coefficient of friction, R_{eff} is the effective radial of the clutch plate, and n_{4c} is the number of friction surfaces. For example, the effective radial of the clutch plate may be based on an inside and/or outside radius of the clutch plate. During an upshift, the control module **28** tracks the total volume of the applying element **76**. The total clutch volume is $V_{24}=V_{f24}+V_{a24}$, where V_{f24} is the fill volume of the applying element **76** and V_{a24} is the accumulator instantaneous volume. The fill volume of the applying element **76** is the volume of oil present before the pressure of the oil begins to compress the spring of the accumulator **48**. The accumulator instantaneous volume is the volume of oil beyond the fill volume required for the applying element **76** to hold the transmission **60** in 2^{nd} gear.

Substituting the relationships from the torque and pressure equations into the equation for total applying element volume produces an equation for the target volume V_{24} of the applying element **76** during a 1-2 upshift. The target volume is:

$$V_{24} = \frac{A_a^2}{K_a}\left(\frac{1}{P_{4c}A_p\mu_f R_{eff}n_{4c}}\left\{\frac{C_1T_t - C_2T_{LR} -}{[C_3(I_T+I_{S2})+C_4I_{S1}]\alpha_o}\right\} - P_{MIN}\right) + V_{amin} + V_{f24}.$$

According to an exemplary embodiment of the present invention, the control module **28** computes a solenoid duty cycle that produces a flow rate of oil capable of filling the applying element **76** to the target volume within a predetermined time period.

Performing upshifts in a fixed time period improves the stability of the transmission **60** and creates more predictable results. However, simply fast-filling the applying element **76** to the target volume after the torque of the releasing element **78** drops produces unstable results. Therefore, in order to guarantee a smooth torque handover between the releasing and applying elements **78** and **76**, respectively, the duty cycle of the solenoid **54** is controlled so that the flow rate to the applying element **76** is variable and exponentially decreases until the target volume is reached. In an exemplary embodiment, the flow rate to the applying element **76** is

$$Q_{24} = -\frac{V_{24}-V_{f24}}{\tau_2\left(1-e^{-\frac{\tau_1}{\tau_2}}\right)}e^{-\frac{t}{\tau_2}}.$$

The continuously variable flow rate Q_{24} can be interpreted as including two separate terms. The first term represents a speed-based initial acceleration. Depending on different initial and targeted speeds, the first term is capable of generating different initial accelerations. The second part represents a continuous acceleration change rate, which provides a predetermined time from initial to targeted gear speeds as well as a smooth acceleration rate. Since the desired acceleration is directly associated with clutch control torque, a very small and gradual change in acceleration may be interpreted as quasi-steady-state. In effect, this improves the quality and control ability of the feedback in the control system **22**.

The continuously variable flow rate Q_{24} originates from an exponential decay rate

$$Q_{24} = A\frac{V_j - V_{f24}}{\tau_1}e^{-\frac{t}{\tau_2}},$$

where τ_1 is the desired duration of the torque phase and τ_2 is the decay rate of the flow rate as the target volume is achieved. As discussed above, the torque phase continues from the time when the applying element **76** is at a minimum torque to the time when the applying element **76** completely takes over the load. For example, the turbine speed changes and reflects the new gear when the applying element **76** takes over the load.

From the start to the finish of the torque phase, the volume of the applying element **76** meets the condition

$$\begin{aligned} V_{24} - V_{f24} &= \int_0^{\tau_1} Q_{24}\,dt \\ &= \int_0^{\tau_1} A\frac{V_{24}-V_{f24}}{\tau_1}e^{-\frac{t}{\tau_2}}\,dt \\ &= A\frac{V_{24}-V_{f24}}{\tau_1}\tau_2\left(1-e^{-\frac{\tau_2}{\tau_2}}\right). \end{aligned}$$

In other words, the difference between the target volume and the fill volume is equal to the integral of the flow rate to the applying element **76** for the duration of the torque phase. From the equation, the constant A is expressed as

$$A = \frac{\tau_1}{\tau_2\left(1-e^{-\frac{\tau_2}{\tau_2}}\right)}.$$

The control module **28** tracks the target volume V_{24} during every normal upshift and compares it to a previously stored target volume value associated with the same position of the throttle blade **40** and/or turbine output torque. For example, turbine output torque and transmission input torque according to the present invention are analogous and may optionally be utilized instead of throttle position for transmission control. Therefore, different target volume values are stored for different positions of the throttle blade **40** during upshifts. When the difference between a current target volume and a previously stored target volume at the same throttle position THR is greater than a predetermined value, the control module **28** updates the target volume value. For example, the control module **28** may add or subtract a percent of the difference between the current and previously stored target volume values.

Additionally, the control module **28** monitors the duration of the torque phase to determine whether the torque phase exceeds a predetermined and fixed amount of time. For example, the fixed amount of time may be 0.5 seconds and may also apply to all shifts. If the time from the beginning of a shift until the beginning of the inertia phase is longer or shorter than the fixed amount of time by a predetermined value, the control module **28** fine tunes a previously stored target volume value. For example, the control module **28** may increase or decrease the stored target volume value by a percent of the difference between a current torque phase duration and the desired torque phase duration.

Referring now to FIG. **5** and using the above models, the transmission control system **22** according to the present invention performs transmission upshift control according to a fast fill phase **102**, a target volume based torque phase **104**, and an inertia phase **106**. As above, the following strategy and equations apply to a 1-2 upshift operation. However, analogous calculations are applied to other upshifts. The torque of the releasing element **78** while holding the transmission **60** in 1^{st} gear is $T_{LR}=C_5T_t-[C_6(I_T+I_{S2})+C_7I_{S1}]\alpha_o$. The control module **28** continuously monitors the position of the throttle blade **40** and/or a position of an accelerator pedal as well as the output speed of the transmission **60** to detect when an upshift to 2^{nd} gear is appropriate.

Once the control module **28** determines that an upshift is necessary, the fast fill phase **102** begins. During the fast fill phase **102**, the duty cycle of the solenoid **54** associated with the applying element **76** is set to a high duty cycle setting and the applying element **76** rapidly begins to fill with oil (identified by a steep increase in volume **108**). For example, the high duty cycle setting (identified by **110**) may be 100%. Additionally, a clock begins to increment at the beginning of the fast fill phase **102** to track the duration t_t of the upshift. Initially, a duty cycle (identified by **112**) of a solenoid associated with the releasing element **78** is also set to a high duty cycle setting. The releasing element **78** is released when the value of the clock t is greater than a predetermined time t_v. In an exemplary embodiment, the predetermined time t_v is equal $t_{dc}-t_r$, where $t_r=K_s(t_s-t_{sr})-C_8$. Although the time at which the releasing element **78** is released is fixed, the fixed time may vary based on line pressure and/or fluid temperature in the transmission **60** and may also vary for other clutches **70**, **72**, **74**, and **76** in the transmission **60**.

The predetermined time to release the releasing element **78** may also be based on line pressure and/or fluid temperature in the transmission **60**. In the function, t_{dc} is the predetermined duration of the fast fill phase **102**, K_s is the learned time-to-slip adjustment for the releasing element **78**, t_s is a look-up table value for the nominal observed release time from the initial venting of the releasing element **78**, and t_{sr} is the time-to-slip reduction for a change-minds shift.

The fast fill phase **102** ends and the target volume based torque phase **104** begins when the term t_f (or the time remaining to nearly fill the applying element **76**) is less than or equal to zero. In an exemplary embodiment,

$$t_f = \frac{V_f - V}{MQ_f} - C_f K_f,$$

where C_f is the time from the beginning of the target volume based torque phase **104** to when the fill volume V_f of the applying element **76** is reached and K_f is a duty cycle compensation factor for a reduced fill rate.

Once the target volume based torque phase **104** begins, the control module **28** adjusts the duty cycle **110** of the solenoid **54** so that the duty cycle **110** begins to exponentially decrease. The duty cycle DC_a is based on the exponentially decreasing flow rate according to

$$DC_a = 100\frac{Q_{24} - Q_r}{MQ_a - Q_r},$$

where

$$Q_{24} = -\frac{V_{24} + \Delta V - V_{f24}}{\tau_2\left(1 - e^{-\frac{\tau_1}{\tau_2}}\right)} e^{-\frac{t}{\tau_2}},$$

Q_r is the releasing element **78** flow rate, Q_a is the applying element **76** flow rate, and M is a line pressure factor. For example, the applying and releasing element flow rates Q_a and Q_r, respectively, may be look-up table values based on a current volume of the oil. The term ΔV is added to ensure that the flow rate of oil to the applying element **76** is always greater than zero, even after the target volume V_{24} is achieved.

In an exemplary embodiment and as discussed above, the initial target volume V_{24} is determined according to

$$V_{24} = \frac{A_a^2}{K_a}\left\langle \frac{1}{P_{4c} A_p \mu_f R_{eff} n_{4c}} \left\{ \begin{array}{c} C_1 T_t - C_2 T_{LR} - \\ [C_3(I_T + I_{S2}) + C_4 I_{S1}]\alpha_o \end{array} \right\} - P_{MIN} \right\rangle + V_{amin} + V_{f24}.$$

The target volume based torque phase **104** ends and the inertia phase **106** begins when the torque of the applying element **76** causes a change in turbine speed N_t. The control module **28** detects a change in turbine speed according to $N_t<N_i-B$, where N_i is the turbine speed during the target volume based torque phase **104**. In other words, the control module **28** detects when the turbine speed decreases by a predetermined speed B.

Alternatively or additionally, the control module **28** detects a change in turbine speed according to $\alpha_{tf}<k_{\alpha d}\alpha_{ij}$, where α_{tf} is the filtered turbine acceleration, $k_{\alpha d}$ is a predetermined factor, and α_{ij} is the desired upshift acceleration. In other words, the control module **28** detects when the turbine acceleration comes within a predetermined range of the desired turbine acceleration.

At that time, the total volume V_{24} is learned with respect to the current position of the throttle blade **40** and/or the turbine output torque. In an exemplary embodiment, the total volume is also learned with respect to the current input torque of the transmission **60**. The control module **28** also compares the upshift time t_t to the desired shift duration when the inertia phase **106** begins, and any discrepancy may be used to update the estimated fill volume V_{f24} of the applying element **76**.

During the inertia phase **106**, the targeted volume control for desired acceleration is expressed according to

$$\frac{\Delta T_{24}}{\Delta t} = C_1 \frac{\Delta T_t}{\Delta t} - [C_2(I_T + I_{S2}) + C_3 I_{C1} + C_4 I_{S1}] \frac{\alpha_{dt} - \alpha_t}{\Delta t}.$$

However, since the solenoid duty cycle is the actual control force that changes the torque of a clutch, the relationship between torque and flow rate is examined. The relationship between accumulator pressure and flow rate is expressed according to

$$Q_{DC} = \frac{\Delta V_a}{\Delta t} = \frac{A_a^2}{K_a}\frac{\Delta P_{24}}{\Delta t}.$$

Then, the torque on clutch is determined according to $T_{24}=P_{24}A_p\mu_f R_{eff} n_{24}$. All of the torque, pressure, and acceleration relationships are substituted to determine the target volume control duty cycle flow rate according to

$$Q_{DC} = \frac{A_a^2}{\mu_f K_a R_{eff} N_{24} A_p}\left\{C_1 \frac{\Delta T_t}{\Delta t} - [C_2(I_T + I_{S2}) + C_3 I_{C1} + C_4 I_{S1}] \frac{\alpha_{\Delta t} - \alpha_t}{\Delta t}\right\}.$$

Desired acceleration is a look-up table value based on the output speed of the transmission **60**, the anticipated position of the throttle blade **40** and the targeted shift gear.

Referring now to FIG. **6**, a target volume algorithm begins in step **118**. In step **120**, the control module **28** reads the current position THR of the throttle blade **40** and the output speed N_o of the transmission **60** and initializes a clock to zero. In step **122**, control determines whether an upshift operation is required. If false, control returns to step **120**. If true, the control module **28** starts the clock in step **124**. Step **124** proceeds to both steps **126** and **128**, and steps **126** and **128** are executed simultaneously and in a parallel format. In step **128**, the control module **28** reads the current value of the clock. In step **130**, control determines whether the value of the clock is greater than or equal to the predetermined venting time t_v. If false, control returns to step **128**.

If true, the control module **28** vents the releasing element **78** in step **132**. In step **134**, control determines whether the current turbine speed is lower than the initial turbine speed. If true, control proceeds to step **136**. If false, control determines whether the current turbine speed is greater than the initial turbine speed in step **138**. If false, control returns to step **134**. If true, the control module **28** reapplies the release element **78** in step **140**. In step **142**, control determines whether the current turbine speed is less than or equal to the initial turbine speed. If false, control loops to step **142**. If true, control returns to step **132**.

In step **126**, the control module **28** reads the current value of the clock. In step **144**, the control module **28** computes the current time left to nearly fill the applying element **76** t_f. In step **146**, control determines whether the current value of the clock is greater than or equal to $(t_r - t_f)$. If false, control returns to step **126**. If true, the control module beings to fast fill the applying element **76** in step **148**. In step **150**, the control module **28** computes the current time left to nearly fill the applying element **76** t_f. In step **152**, control determines whether t_f is less than or equal to zero. If false, control returns to step **150**. If true, the control module **28** adjusts the solenoid **54** duty cycle so that the duty cycle exponentially decays in step **154**. In step **156**, control determines whether the turbine speed is less than the initial gear speed.

If false, control loops to step **156**. If true, the control module **28** initiates the inertia phase **106** in step **136**. The control module **28** also optionally adjusts a previously stored total volume associated with the current input torque of the transmission **60** or the current position of the throttle blade **40** THR when the difference between the current and previous values is greater than a predetermined value. In step **158**, control determines whether the current turbine speed is equal to the target turbine speed. If false, control loops to step **158**. If true, control ends.

The above-described means for detecting the target volume within the fluid system can be used in part to detect a fill volume V_f of an accumulator **10**. For instance, FIG. **7** is a graph showing the throttle position on the X-axis and the volume of fluid within the clutch on the Y-axis. In the embodiment shown, data points **160**, **162**, **164**, **166**, **168** each represent different target volumes of an accumulator detected at different throttle positions. The control module **28** detects these target volume data points **160**, **162**, **164**, **166**, **168** in the manner described above. The control module **28** extrapolates a current fill volume, V_f, from at least one of the detected target volume data points **160**, **162**, **164**, **166**, **168**.

More specifically, in the embodiment represented in FIG. **7**, the control module **28** extrapolates the current fill volume V_f with a linear function relating the fill volume, V_f, the detected target volume, V_t, a predetermined slope, C_1, and the throttle position, THR_t. The linear function for the embodiment shown in FIG. **7** is expressed as:

$$V_t = C_1(THR_t) + V_f$$

Solving for the current fill volume, the equation becomes:

$$V_f = V_t - C_1(THR_t)$$

The slope, C_1, is predetermined based on the spring rate of the spring **12** within the accumulator **10** and/or other factors. Thus, once the target volume, V_t, for a known throttle position, THR_T, the control module **28** is able to calculate the current fill volume V_f. It will be appreciated, however, that the control module **28** could extrapolate the current fill volume from the target volume in any suitable manner without departing from the scope of the present disclosure.

In one embodiment, when the difference between the current fill volume, V_f, and a previously stored fill volume is greater than a predetermined value, the control module **28** updates the fill volume. For example, the control module **28** adds or subtracts a percentage of the difference between the current and previously stored fill volume values. Accordingly, the control module **28** can more accurately control the transmission because the fill volume used by its control logic is more likely to be accurate and up to date.

Furthermore, in one embodiment, the control module **28** only extrapolates the current fill volume during a shift at which the throttle position is less than a predetermined value. Accordingly, the current fill volume can be detected more accurately at these lower throttle positions.

It will be appreciated that the control module **28** could extrapolate the current fill volume based on the transmission input torque, rather than the throttle position in the same manner described above. More specifically, the control module **28** can extrapolate the current fill volume V_f with a linear function relating the fill volume, V_f, the detected target volume, V_t, a predetermined slope, C, and the transmission input torque, IT_t. This function is expressed as:

$$V_f = V_t - C(IT_t)$$

Thus, once the target volume, V_t, for a known transmission input torque, IT_t, the control module **28** is able to calculate the current fill volume V_f. In one embodiment, the control module **28** only extrapolates the current fill volume, V_f, during a shift at which the transmission input torque, IT_t, is less than a predetermined value for more accurate detection of the current fill volume, V_f.

In one embodiment, fill volumes are detected in this manner for less than all of the gears within a transmission. For the other gear(s), the fill volume is detected only during a downshift. For instance, in the embodiment of FIG. **3**, clutch **78** acts as the applying clutch during a downshift from a higher gear to a lower gear (e.g., from second gear to first gear). Thus, for clutch **78**, the control module **28** detects a fill volume for the clutch **78** during downshift only.

More specifically, a downshift is represented graphically in FIG. **8**. Line **170** represents the turbine speed, N_t, and line **172** represents the acceleration of the turbine, α_t. Also, dashed line **174**, N_j, represents the turbine speed for achieving the gear ratio of the lower gear. As shown by line **170**, before the downshift occurs, the turbine speed, N_t, increases and eventually exceeds the turbine speed, N_j. Then, at point **176** (represented on both lines **170** and **172**), the turbine speed, N_t, begins to exhibit a negative rate of change (i.e., the turbine decelerates). At point **176**, clutch **78** begins to produce torque for achieving the downshift. Thus, at point **176**, the control module **28** detects the volume in the accumulator **10**, and this detected volume represents a close approximation of the fill volume for clutch **78**. In one embodiment, the control module **28** includes a predetermined offset for adjusting the detected volume to account for any difference between the detected volume and the actual fill volume for the clutch **78**. If the difference between this adjusted fill volume and the previously stored fill volume exceeds a predetermined amount, the previously stored value can be updated as described above. Accordingly, the fill volume of clutch **78** can also remain more accurate.

Referring now to FIG. **9**, a method **178** of detecting the current fill volumes described above is illustrated. In one embodiment, the method **178** is used for transmissions that include PWM solenoids and/or transmissions that use solenoids to directly control the respective clutches.

The method **178** begins in step **180**, in which the throttle position and the vehicle speed are detected. The method **178** continues in decision block **182**, in which it is determined whether a gear shift is required. If a gear shift is not required, the method **178** returns to step **180**. If a gear shift is required, the method **178** continues to decision block **184**.

In decision block **184**, it is determined whether an upshift is necessary. If an upshift is necessary, the method **78** continues to decision block **186**, in which it is determined whether a low throttle condition exists. As mentioned above, the control module **28** can detect fill volumes more accurately at low throttle positions. Thus, as shown in FIG. **9**, if a low throttle condition does not exist, the method **178** ends. However, if a low throttle condition does exist, the method **178** moves to step **188**.

In step **188**, the control module **28** begins to vent the oil from the release element. Subsequently, in step **190**, the control module **28** tracks the volume of fluid within the applying element, and the target volume, V_t, is detected as described above.

Next, in step **192**, the control module **28** extrapolates the current fill volume V_f from the detected target volume, V_t as described above. Finally, in step **194**, the control module **28** updates the stored fill volume. As mentioned, in one embodiment, the stored fill volume is updated only when the difference between the stored fill volume and the current fill volume exceeds a predetermined value.

Referring back to decision block **184**, if a downshift occurs, the method **178** moves to decision block **196**. In decision block **196**, it is determined whether it is time to begin filling the applying clutch (e.g., clutch **78** from FIG. **3**). In one embodiment, the decision block **196** occurs according to the disclosure of U.S. Pat. No. 6,978,201, which issued on Dec. 20, 2005, and which is incorporated herein by reference. If it is not time to fill the applying clutch, decision block **196** loops back on itself. When it is time to begin filling the applying clutch, the method **178** continues to step **198**, in which the control module **28** tracks the volume of the applying clutch. Then, in decision block **200**, it is determined whether the turbine shows a negative acceleration. If not, then decision block **200** loops back on itself. If a negative acceleration is detected, then the method **178** moves to step **202** and detects the volume in the applying clutch (i.e., a close approximation of the fill volume, V_f, of the applying clutch). As stated above, the control module **28** can include a predetermined offset to adjust the detected volume for a more accurate fill volume of the applying clutch. Then, the method **178** moves to step **194**, in which the stored fill volume is updated.

In sum, the present disclosure reveals a means for maintaining accurate fill volumes for the clutches in a transmission. This allows the transmission to maintain smooth gear shifting over the life of the vehicle.

The above discussion is merely exemplary in nature and, thus, variations that do not depart from the gist of the disclosure are intended to be within the scope of the disclosure. Such variations are not to be regarded as a departure from the spirit and scope of the disclosure.

What is claimed is:

1. A transmission control system for a transmission including a first gear engagement element that receives a fluid and engages a first gear in response to pressure from the fluid, the system comprising:

an electromagnetic actuator that receives a control signal and that selectively interrupts flow of the fluid to the first gear engagement element based on a value of the control signal; and

a control module that generates the control signal and that adjusts the value of the control signal so that the first gear engagement element produces a first torque sufficient to hold the first gear, wherein the control module detects a target volume of the fluid when the first gear engagement element produces the first torque, and wherein the control module extrapolates a current fill volume of the first gear engagement element from the target volume, the current fill volume being a volume at which the first gear engagement element begins to produce torque during a shift.

2. The transmission control system of claim **1**, wherein the control module adjusts a value of a previously stored fill volume for subsequent transmission control when a difference between the current fill volume and the previously stored fill volume is greater than a predetermined value.

3. The transmission control system of claim **1**, wherein the control module only extrapolates the current fill volume during a shift at which at least one of a position of a throttle blade is less than a predetermined value and a transmission input torque is less than a predetermined value.

4. The transmission control system of claim **1**, wherein the transmission includes a second gear engagement element that includes a first volume of fluid before a shift is initiated, and wherein, after initiating the shift, the control module begins to evacuate the first volume of fluid from the second gear engagement element before computing the target volume.

5. The transmission control system of claim **1**, wherein the control module extrapolates the current fill volume with at least one linear function relating the fill volume, the target volume, a predetermined slope, and at least one of a throttle position and a transmission input torque, the at least one linear function chosen from a group consisting of:

Fill Volume=Target Volume−Slope(Throttle Position); and

Fill Volume=Target Volume−Slope(Transmission Input torque).

6. The transmission control system of claim **1**, wherein the transmission includes a second gear engagement element that receives the fluid and engages a second gear, and wherein the control module detects a fill volume of the second gear engagement element by detecting a current volume of the fluid received by the second gear engagement element when the second gear engagement element begins to produce torque during a shift.

7. The transmission control system of claim **6**, wherein the second gear engagement element begins to produce torque when a turbine speed begins to exhibit a negative rate of change during the shift.

8. The transmission control system of claim **6**, wherein the transmission is an automatic transmission of a vehicle, wherein the first gear engagement element is an applying clutch that is applied during an upshift from a lower gear to a higher gear, and wherein the second gear engagement element is an applying clutch that is applied during a downshift from a higher gear to a lower gear.

9. The transmission control system of claim **1**, wherein the transmission includes a second gear engagement element that receives fluid and engages a second gear during a downshift and wherein the control module detects a fill volume of the second gear engagement element only during the downshift.

10. A transmission control system for a transmission including first and second gear engagement elements that receive fluid and engage first and second gears, respectively, in response to pressure from the fluid, the transmission control system comprising:

an electromagnetic actuator that receives a control signal and that selectively interrupts flow of the fluid to the first gear engagement element based on a value of the control signal; and

a control module that generates the control signal and that adjusts the value of the control signal so that the first gear engagement element produces a first torque sufficient to hold the first gear during an upshift;

wherein the control module detects a target volume of the fluid when the first gear engagement element produces the first torque, and wherein the control module extrapolates a current fill volume of the first gear engagement element from the target volume, the current fill volume being a volume at which the first gear engagement element begins to produce torque during a shift;

wherein the control module detects a current fill volume of the second gear engagement element by detecting a current volume of the fluid received by the second gear engagement element when the second gear engagement element begins to produce torque during a downshift; and

wherein the control module only extrapolates the current fill volume of the first gear engagement when at least one of a position of a throttle blade is less than a predetermined value and a transmission input torque is less than a predetermined value.

11. The transmission control system of claim **10**, wherein the control module adjusts a value of a previously stored fill volume for at least one of the first and second gear engagement elements for subsequent transmission control when a difference between the current fill volume and the previously stored fill volume for the at least one of the first and second gear engagement elements is greater than a predetermined value.

12. A method for operating a transmission control system for a transmission including a first gear engagement element that receives fluid and engages a first gear in response to pressure from the fluid, the method comprising the steps of:

selectively interrupting flow of the fluid to the first gear engagement element based on a value of a control signal;

adjusting the value of the control signal so that the first gear engagement element produces a first torque sufficient to hold the first gear;

detecting a target volume of the fluid when the first gear engagement element produces the first torque; and

extrapolating a current fill volume of the first gear engagement element from the target volume, the current fill volume being a volume at which the first gear engagement element begins to produce torque during a shift.

13. The method of claim **12**, further comprising the step of adjusting a value of a previously stored fill volume for subsequent transmission control when a difference between the current fill volume and the previously stored fill volume is greater than a predetermined value.

14. The method of claim **12**, further comprising only extrapolating the current fill volume during a shift when at least one of a position of a throttle blade is less than a predetermined value and a transmission input torque is less than a predetermined speed.

15. The method of claim **12**, further comprising the steps of:

providing a second gear engagement element that includes a first volume of fluid before a shift is initiated;

initiating the shift; and

beginning to evacuate the first volume of fluid from the second gear engagement element before detecting the target volume.

16. The method of claim **12**, wherein the step of extrapolating a current fill volume comprises extrapolating the current fill volume with at least one linear function relating the fill volume, the target volume, a predetermined slope, and at least one of a throttle position and a transmission input torque, the at least one linear function chosen from a group consisting of:

Fill Volume=Target Volume−Slope(Throttle Position); and

Fill Volume=Target Volume−Slope(Transmission Input Torque).

17. The method of claim **12**, further comprising the steps of:

providing a second gear engagement element that receives the fluid and engages a second gear; and

computing a fill volume of the second gear engagement element by computing a current volume of the fluid received by the second gear engagement element when the second gear engagement element begins to produce torque during a shift.

18. The method of claim **17**, wherein the second gear engagement element begins to produce torque when a turbine speed begins to exhibit a negative rate of change during the shift.

19. The method of claim **17**, wherein the transmission is an automatic transmission of a vehicle, the first gear engagement element is an applying clutch that is applied during an upshift from a lower gear to a higher gear, and the second gear engagement element is an applying clutch that is applied during a downshift from a higher gear to a lower gear.

20. The method of claim **12**, further comprising the steps of:

providing a second gear engagement element that receives fluid and engages a second gear during both an upshift and a downshift; and

detecting a fill volume of the second gear engagement element only during the downshift.

* * * * *